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Effect of Polymer Coatings on Fatigue Strength of Aluminum Alloy 2024 Box Beams

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EFFECT OF POLYMER COATINGS ON FATIGUE STRENGTH OF ALUMINUM ALLOY 2024 BOX BEAMS

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FOREWORD

This investigation was conducted by the Alcoa Research Laboratories, Aluminum Company of America, New Kensington, Pennsylvania, under NASA Contract No. NA52-6415. The work was under the direction of the Materials Research Branch of NASA-Ames Research Center, Moffett Field, California with Dr. H. T. Sumsion as project engineer.

This final report covers work done from April, 1971, through May, 1972.

ABSTRACT

Previous investigators have shown that polymer coatings raise the fatigue strength of metals tested in air to about the same level as that of uncoated specimens tested in vacuum. This report gives the results of tests to determine if a polymer coating would improve the fatigue strength of built-up aluminum alloy members simulating aircraft construction. Aluminum alloy 2024-T4 riveted box beams were subjected to constant amplitude fatigue tests in air as well as in salt water fog. The coating did not improve the fatigue strength of beams tested in either environment. This is believed to result from the fact that most failures originated at rivet holes, which were isolated from both the coating and the environment.

EFFECT OF POLYMER COATINGS ON THE FATIGUE STRENGTH OF ALUMINUM ALLOY 2024-T4 BOX BEAMS

I. Introduction

It has long been recognized that metals have a higher fatigue strength when tested in vacuum rather than in air (Ref. 1). Gilde (Ref. 2) showed that epoxy coatings can improve the fatigue strength of welded and unwelded aluminum. Using sheet flexure tests, Sumsion (Refs. 3 and 4) reported that a polymer coating raised the fatigue strength of aluminum alloy, magnesium alloy and magnesium specimens to about the same level as that obtained in vacuum. Because investigations (e.g., Ref. 5) have shown that it is the water vapor in the air that affects fatigue strength of aluminum alloys, Sumsion attributed the improvement in fatigue strength of coated specimens to the exclusion of reactive gas normally present in the atmosphere from the new metal surface created by the fatigue crack. The purpose of the present investigation was to determine if a polymer coating would also improve the fatigue strength of built-up aluminum alloy members simulating aircraft construction.

II. Specimens

It has been demonstrated that the results obtained from flexural fatigue tests of alloy 7075-T6 box-beam specimens of the type shown in Fig. 1 are in good agreement with those obtained from full-scale tests of aircraft structures (Refs. 6-8). Accordingly, similar aluminum alloy box beam specimens were fabricated from alloy 2024 products for this program. Tensile properties of the bars and channels used for the beams are listed in Table 1.

Eleven of the fabricated beams were coated by NASA, Ames Research Center, using Uni-Kote 531* which had been reduced from 23.8% solids as received to 12% solids with a 75% toluene-25% methyl-ethylketone (M.E.K.) solvent solution. The procedure used in coating the beams was as follows:

1. Degreased and flushed with hot trichlorethylene, then solvent washed with M.E.K. and rinsed with methanol.

2. Heated to 165°F for at least 16 hours just prior to dipping.

3. Dipped vertically into the solution and held until formation of bubbles ceased - about 40 seconds - then removed and allowed to dry. Cycle repeated seven times to give 0.003-inch coating.

III. Test Procedures

Two uncoated specimens were tested statically in bending as shown in Fig. 2. The beam was supported on rollers having a 40-in. span. The two load points were located 4-in. on either side of the center of the beam. Fig. 3 shows the relationship between load and tensile strain measured with electrical strain gages on the bottom flange, at the center of the beam.

The flexural fatigue tests were conducted in a 50 kip Templin Fatigue Machine as shown in Fig. 4. The load and

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*Uni-Kote 531 consists of polyurethane in methylethylketone (Universal Protective Coatings, San Rafael, California).

support spans were the same as those used in the static tests. In the static tests the beam was free to rotate at the end supports, while in the fatigue tests the end support fixtures caused some restraint against rotation. This resulted in a difference in load-strain relationships, as shown in Fig. 3. The calibration curves in Fig. 3 were used to determine the maximum load required in the fatigue test to produce tensile strains on the bottom flange equivalent to either 28, 40 or 67 per cent of failure load in the static test. Minimum load in the fatigue tests was equivalent to about 10 per cent of static failure load.

To evaluate the integrity of the coating in a corrosive environment, coated and uncoated specimens were subjected to a 1-minute salt water fogging at 15-minute intervals; for these tests the test section was enclosed in a plastic chamber. Specimens tested in salt fog were loaded at a rate of 15 cpm while specimens tested in air were loaded at a rate of either 15 or 250 cpm.

IV. Results

Test results are presented in Table 2 and Figs. 5 and 6. These data show that the polymer coating did not affect the fatigue lives of box beams tested in either air or salt fog; there was no statistically significant difference in the lives of coated and uncoated specimens tested at 15 cpm in the two environments. In previous investigations (Refs. 3 and 4), where the fatigue lives of polymer coated specimens tested in air were comparable to those of uncoated specimens tested in vacuum, simple specimens were used and the coating was applied over the entire specimen including, of course, the metal at the site of crack initiation. However, in the box beam specimens, the coating was applied to the beams after they had been assembled. It is believed that the fabricating process created a localized test environment in the rivet holes which was independent of the external environment and was not affected by the coating. In addition to some air being trapped in the rivet hole, the holes undoubtedly had some residual machining oils present. The isolation of the rivet holes from the environment in these tests is further evidenced by the fact that in tests of uncoated beams, there was no significant difference in the lives of specimens tested in air or salt fog. Thus, it appears that the coating is not effective when applied to riveted assemblies. However, it is possible that the coating could have improved the fatigue lives of the beams if the coating had been applied to the parts before assembly. Tests would be required to determine this.

Most failures initiated at rivet holes within two rivets from the load points. However, some failures initiated at surface scratches or other imperfections on the tension flange. Generally, the fatigue lives of the latter specimens were higher than those of specimens where the failures initiated at the holes.

Neither the repeated loading nor the salt spray caused any noticeable cracking, crazing or reduction in thickness of the polymer coating.

It can be seen in Fig. 5 that, at a stress of 25 ksi, the lives of the beams cycled at a rate of 15 cpm tend to be shorter than those cycled at 250 cpm. The difference was found to be statistically significant for a 95 per cent confidence level.

The results of the 2024 beam tests reported herein are compared in Fig. 7 with a scatter band representing the results given in Refs. 5 and 6 for 7075-T6 box beams. In spite of the lower static strength of alloy 2024-T4, the fatigue lives at 43 ksi fall within the scatter band for 7075-T6 beams. At the lower stress level, 25 ksi, the lives of the 2024 beams are substantially longer than those for 7075-T6 beams. The advantage for the 2024 beams may result from the fact that the stress concentration is less for two point loading on the top flange than for the single point loading in the webs of the 7075 beams. Tests of other beams at these laboratories have shown that the long-life fatigue strength can be higher for beams loaded through the compression flange than for beams loaded through the web.

V. Conclusions

1. A polymer coating did not improve the fatigue strength of aluminum alloy 2024-T4 riveted box beams tested in air or in a salt fog environment.

2. A salt fog environment did not appreciably shorten the fatigue lives of coated or uncoated beams.

3. The foregoing results are believed to stem from the fact that the rivet holes, where most failures originated, were isolated from both the coating and the environment.

4. The long life fatigue strengths of the 2024-T4 box beams are higher than values reported in the literature for similar 7075-T6 box beams. It is believed that this advantage may result from a difference in loading.

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Table 1

Tensile Properties

Component (see Fig. 1)	Alloy	Tensile Strength, ksi	Yield Strength, ksi	Elong. in 2 in., %
Extruded Channel	2024-T3511	71.1	52.4	21
Minimum*		57	42	12
Rolled Bar	2024-T4	65.9	49.1	18
Minimum*		62	45	10

*Minimum specified values given in Aluminum Standards and Data, 1972-73, The Aluminum Association.

Table 2

RESULTS OF FATIGUE TESTS OF ALUMINUM ALLOY 2024-T4 BOX BEAMS

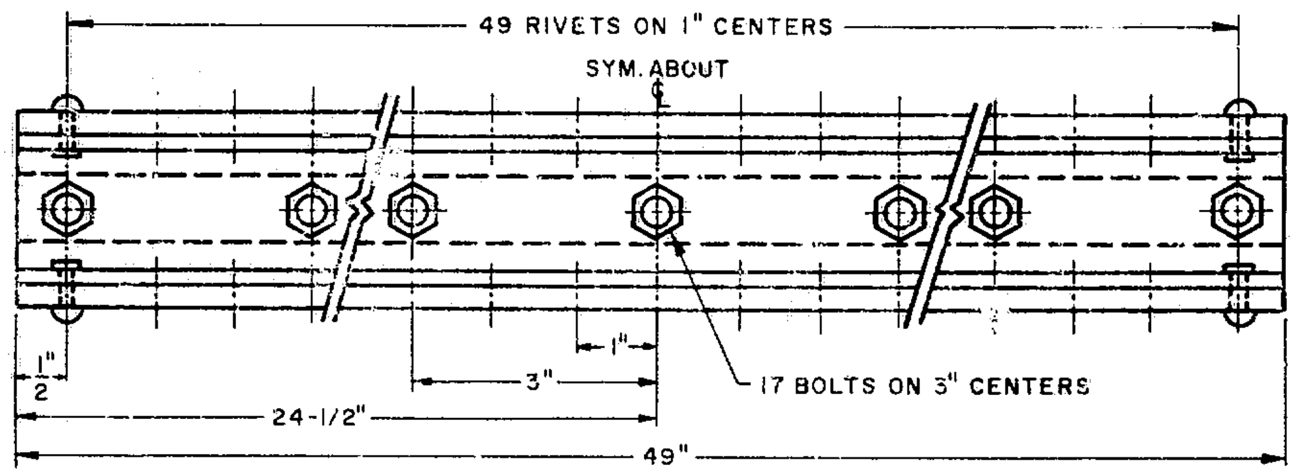
Spec. No.	Environment++	Test Speed, cpm	Actual Load, kips Min.	Actual Load, kips Max.	Max. Bending Stress, ksi	Cycles to Failure	Failure Locations in Flange** Overplate	Failure Locations in Flange** Web
				Uncoated Beams				
13	Air	--	-	7.900	65.1*	Static	Hole-0	Hole-0
12	Air	--	-	7.800	64.3*	Static	Hole-3	Hole-3
14	Air	15	0.837	5.857	43.1*	16,100	Hole-5	Hole-5,4
18	Air	15	0.851	5.861	43.1*	18,500	Between Holes 2&3	Hole-3
15	Air	15	0.838	5.868	43.2*	22,600	Hole-1	-
23	Air	15	0.785	3.365	24.8	400,400	Hole-1	-
16+	Air	250	0.784	3.364	24.8	494,400	Hole-6	Hole-5
17+	Air	250	0.824	3.403	25.0	558,200	Between Holes 3&4	Hole-3
19	Air	250	0.784	3.364	24.8	804,[illegible]00	Between Holes 2&3	Hole-1,3
16	Air	15	0.851	2.207	16.3	833,600	None, load raised	
17	Air	250	0.771	2.196	16.1	5,831,800	None, load raised	
20	Salt Fog	15	0.811	5.851	43.1*	20,500	Hole-6	Hole-5
21	Salt Fog	15	0.771	3.363	24.8	235,700	Hole-5	Hole-5
22	Salt Fog	15	0.784	3.364	24.8	293,000	Between Holes 5&6	Hole-5
				Polymer Coated Beams				
5	Air	15	0.838	5.858	43.1*	15,800	Hole-6	Hole-5
4	Air	15	0.838	5.858	43.1*	16,900	Hole-7	Hole-6
6	Air	15	0.824	5.854	43.1*	21,400	Hole-6	Hole-5
11	Air	15	0.798	3.377	24.9	228,100	Hole-2	-
10	Air	15	0.785	3.377	24.9	282,800	Hole-6	Hole-5
2	Air	250	0.784	3.364	24.8	335,900	Hole-5	Hole-5,4
1	Air	250	0.772	3.352	24.7	464,900	Hole-6	Hole-5
3	Air	250	0.784	3.374	24.9	611,900	Hole-2	Hole-1
7	Salt Fog	15	0.837	5.837	43.0*	19,400	Hole-6	Hole-5
9	Salt Fog	15	0.811	3.389	24.9	129,000	Hole-6	Hole-5
8	Salt Fog	15	0.784	3.364	24.8	233,300	Between Holes 0 & 1	-

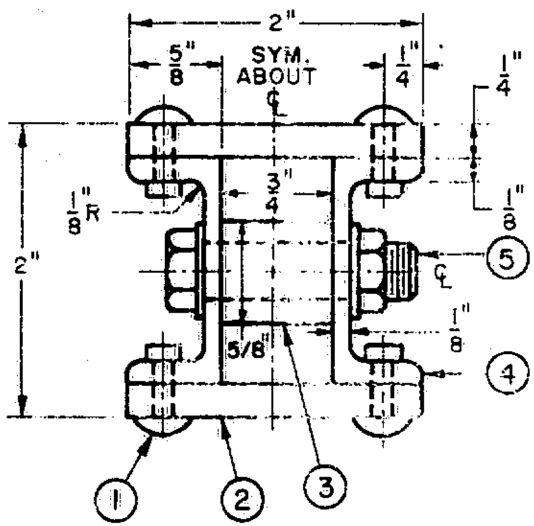
*Apparent bending stress assuming elastic action.

**Hole indicates fatigue cracks initiated in a rivet hole - number indicates number of rivet holes from centerline. Load points were over Hole #4. Other failures initiated on surface of flange between rivet holes, at scratches or other surface imperfections.

+Previous loading.

++Air - ambient laboratory air
Salt Fog - 1 minute salt water fogging at 15-minute intervals.



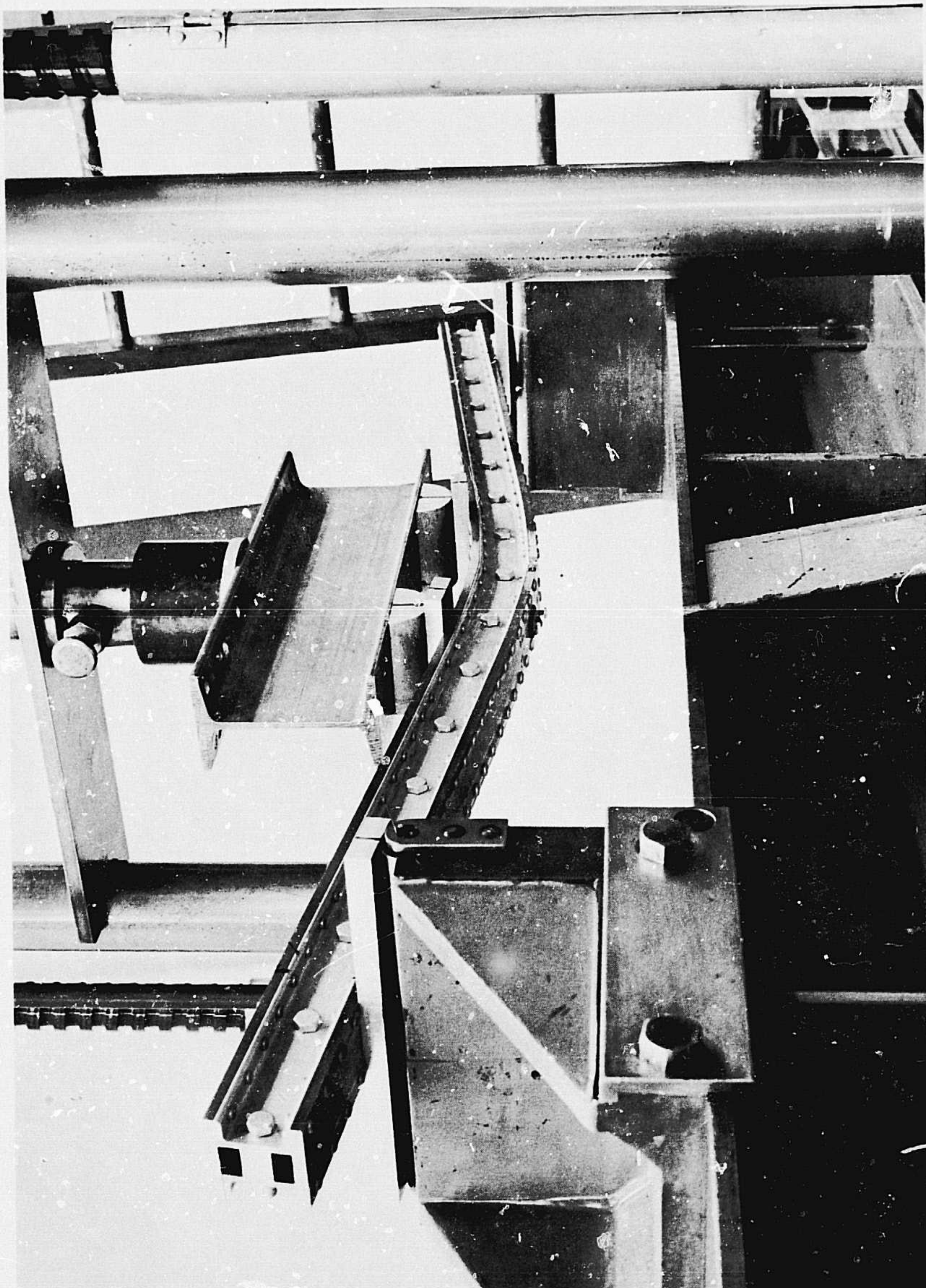


END VIEW - ENLARGED

PART NO.	ITEM	MATERIAL
1	RIVET AN470-DD6-9	2024-T4
2	BAR	2024-T4
3	BAR	2024-T351
4	CHANNEL	2024-T351
5a	BOLT 5/16x1-3/4"	2024-T4
5b	NUT	6262-T9
5c	WASHER AN960-516	ALCLAD 2024-T4

BOX - BEAM SPECIMEN DESIGN

FIG. 1



ALUMINUM ALLOY 2024-T4 BOX BEAM AFTER FAILURE IN STATIC TEST

Fig. 2

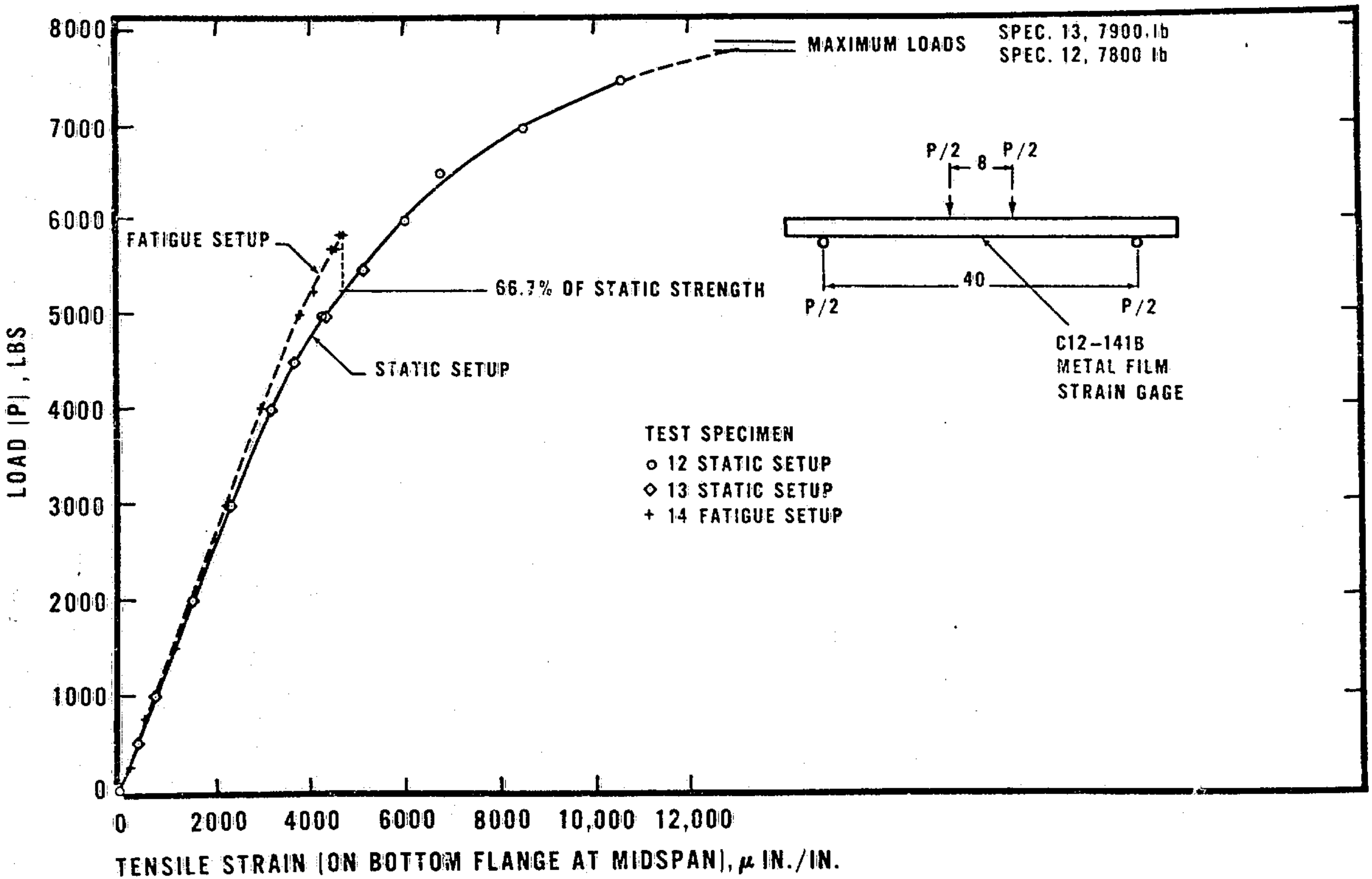
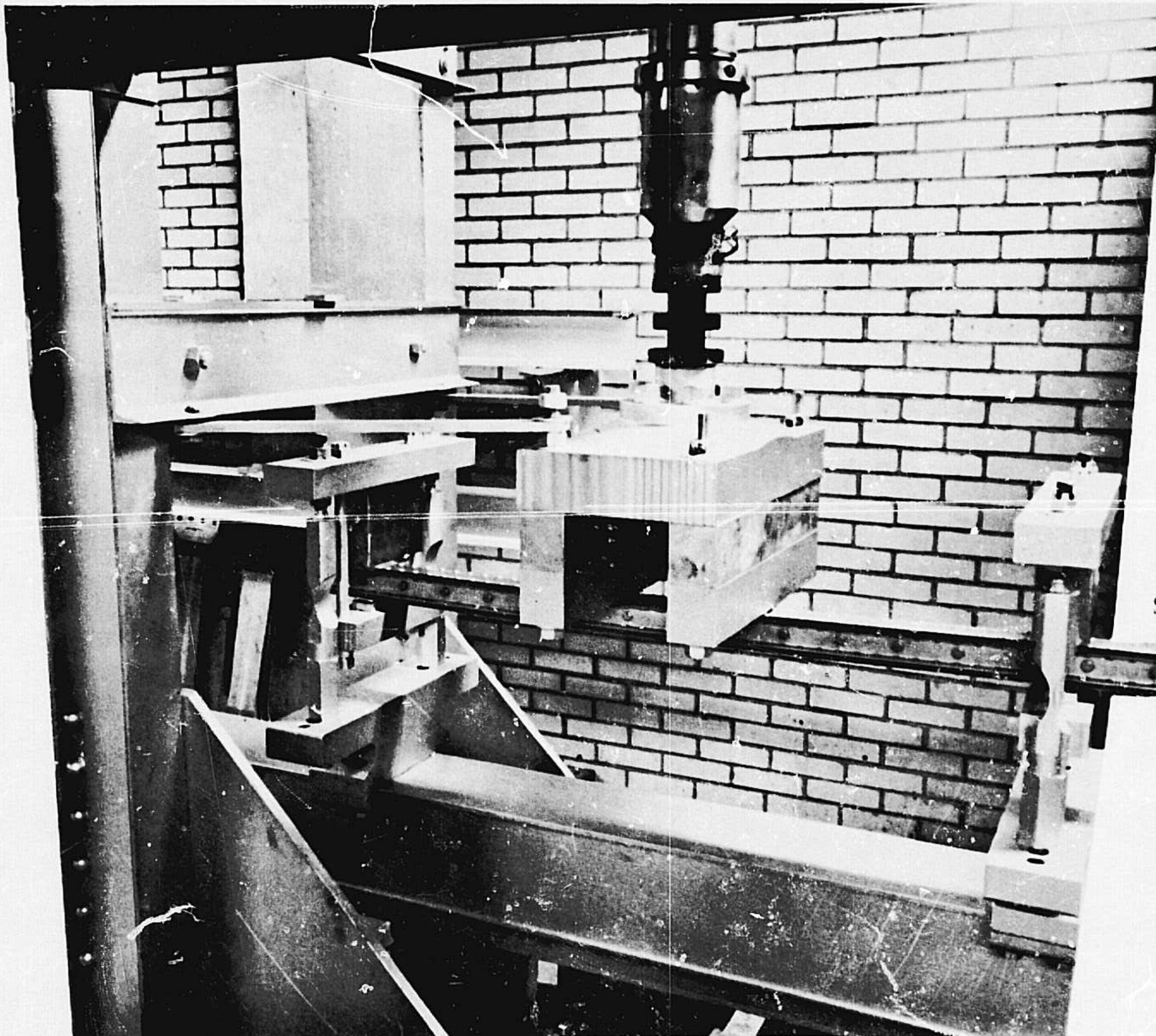
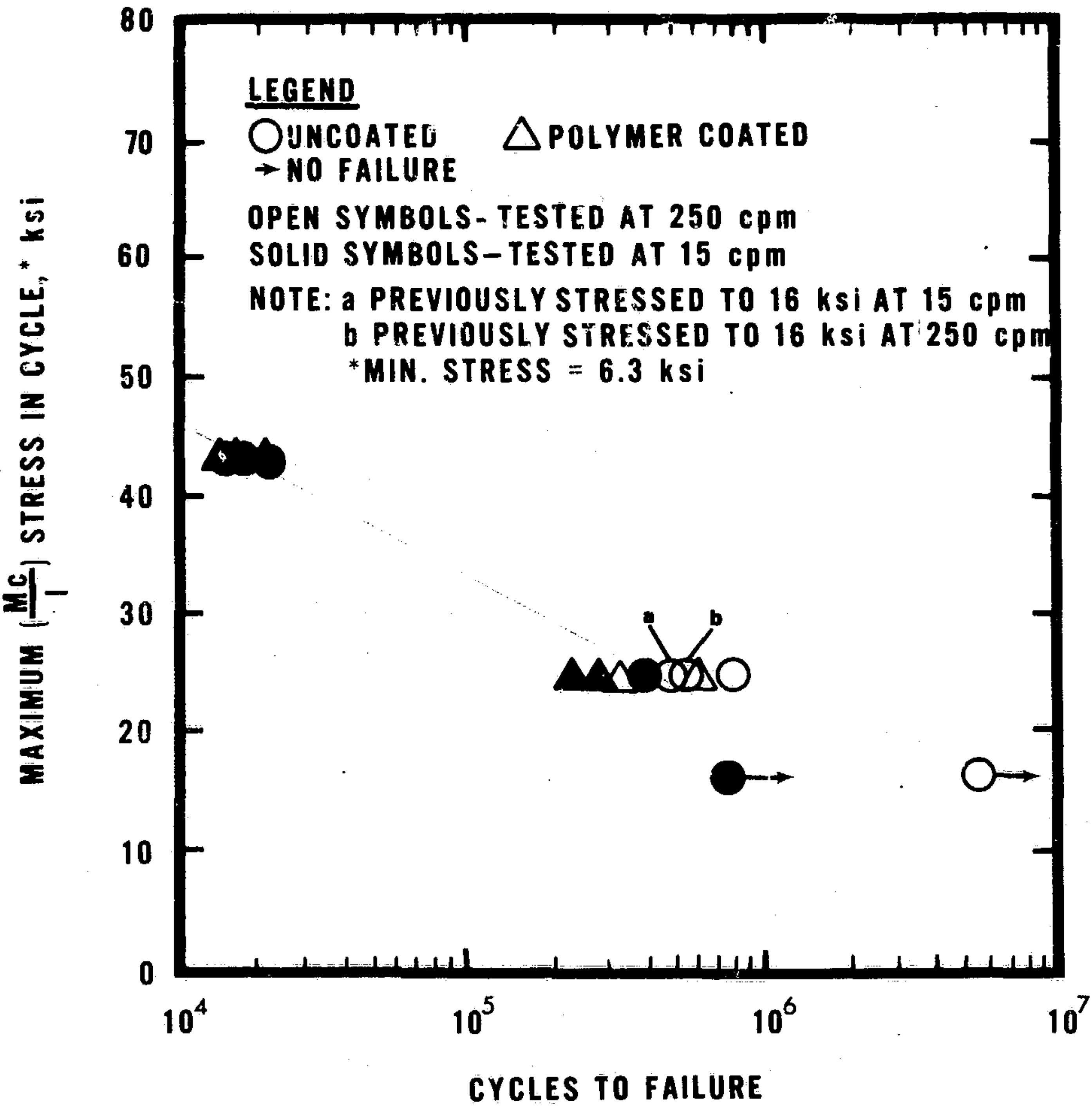


FIG. 3 LOAD–STRAIN RELATIONSHIPS FOR STATIC AND CYCLIC LOADING OF ALUMINUM ALLOY 2024–T4 BOX BEAMS


SPECIMEN

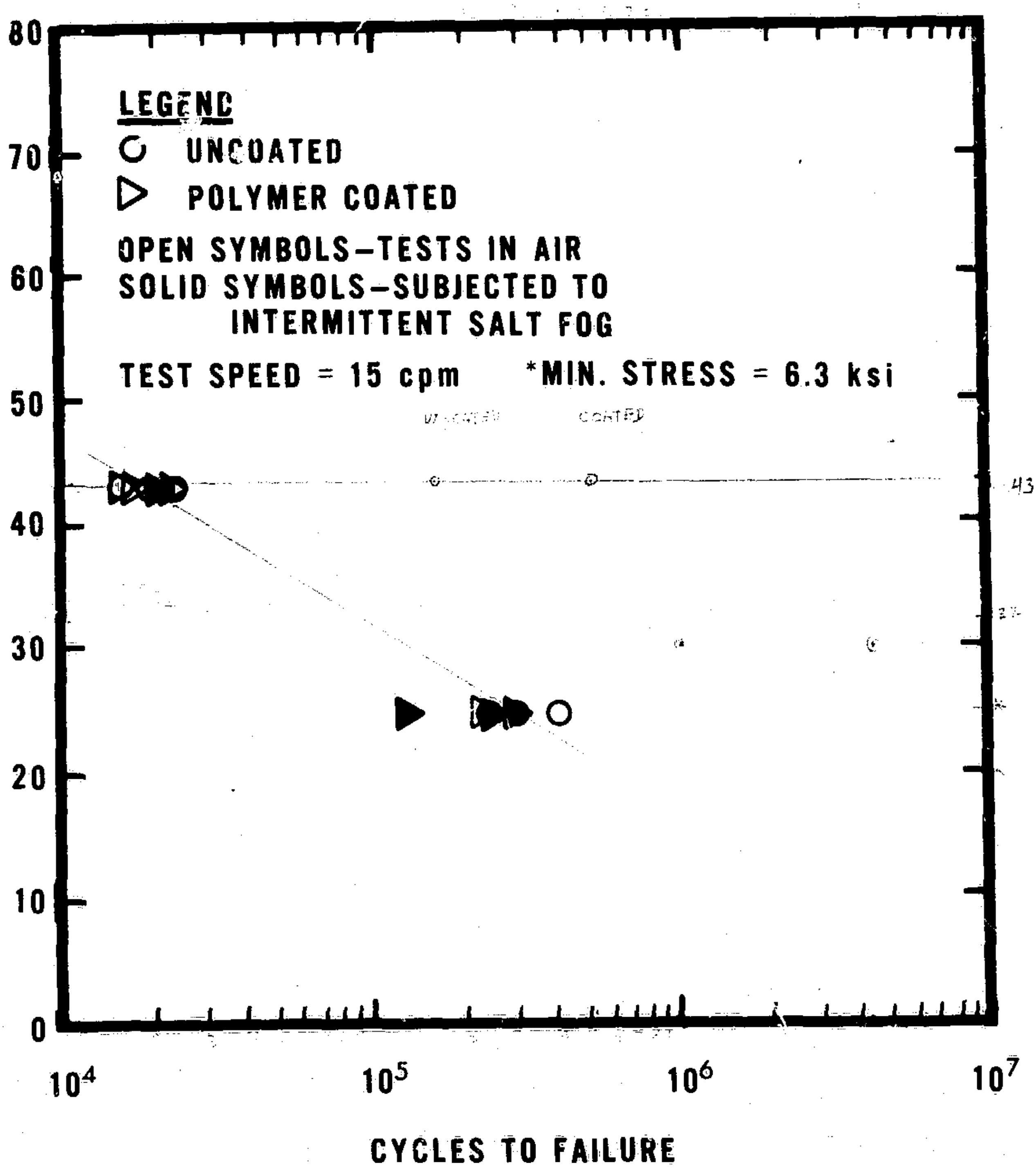
SETUP FOR FATIGUE TEST OF ALUMINUM ALLOY 2024-T4 BOX BEAM SPECIMEN

Fig. 4



EFFECT OF POLYMER COATINGS ON FATIGUE STRENGTH OF ALUMINUM ALLOY 2024–T4 BOX BEAMS TESTED IN AIR

FIG. 5



EFFECT OF SALT FOG ON FATIGUE STRENGTH OF ALUMINUM ALLOY 2024–T4 BOX BEAMS

FIG: 6

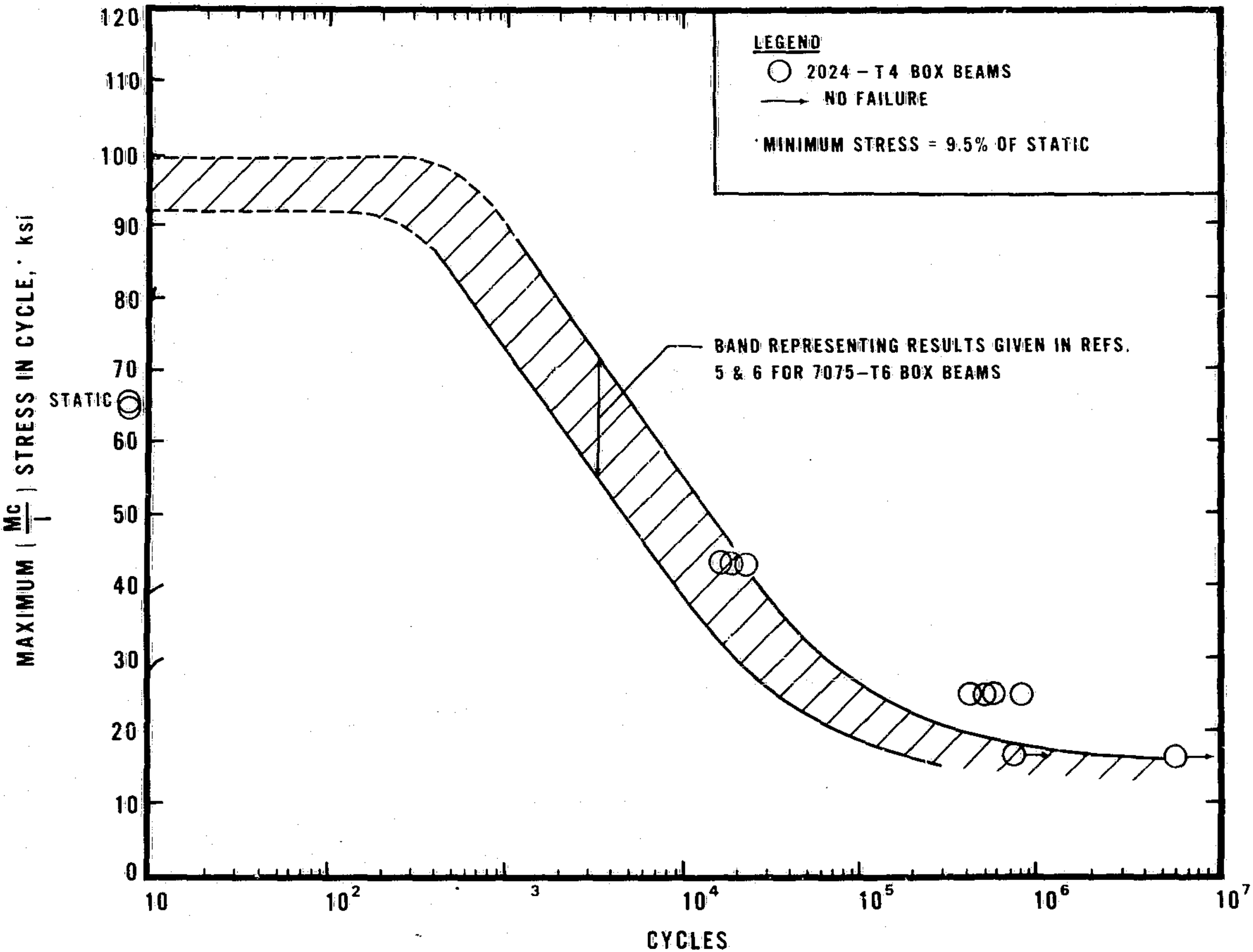


FIG. 7 COMPARISON OF THE FATIGUE STRENGTH OF ALLOY 2024 AND ALLOY 7075 ALUMINUM BOX BEAMS